APPENDIX 5-18

WAVE RUN-UP MODEL DOCUMENTATION MEMORANDUM

BLACK & VEATCH

TECHNICAL MEMORANDUM

South Florida Water Management District
EAA Reservoir A-1
Work Order No. 5

B&V Project 141522
B&V File:C1-3
First Issue: July 11, 2005
Last Updated:

Task 5.3.5.2.2 Model Documentation Memorandum
For Wave Run-up Model

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To: Shawn Waldeck and Rich Bartlett

From: Beth Quinlan

1. OBJECTIVE

The overall objectives of the Wave Run-up Model are as follows:

- To determine the amount of freeboard required to prevent over-topping of the reservoir embankment during high wind and rain conditions
- To determine the effectiveness of internal breakwaters in decreasing wave run-up

The objective of this Draft Model Documentation Memorandum is to describe the Wave Run-up Model and provide input and output files, model documentation, and model user's manual with instructions for set-up of the model.

2. ACES MODEL

The ACES (Automated Coastal Engineering System) program was used to calculate wave growth, wave run-up and wave transmission through internal breakwaters. The calculations were completed using the wave prediction, wave theory, wave run-up, and wave transmission modules of the program. The ACES program does not calculate wind set-up. This was calculated separately using the Sibul method as described in Section 3 of this Technical Memorandum. The ACES Technical Reference which provides the model documentation is provided in Appendix 5-16.

2.1 Model Description

The wave prediction section of the model computes wave growth. Wave growth is a function of the speed and duration of winds, fetch distance, and water depth. The energy associated with the waves is calculated in the wave theory section. The wave run-up section of the model calculates the run-up that occurs when waves encounter a shoreline or embankment. Overtopping rates are also calculated in this module of ACES. The wave transmission section of the ACES model was used to determine the effects that internal breakwaters would have on wave growth, transmission of wave energy through internal breakwaters, and on final wave run-up on the embankments.

2.2 Model Inputs and Assumptions

The case descriptions and design conditions are presented in Appendix 5-17. Input files are included in Appendix 5-18.

2.3 Wave Prediction and Wave Theory

The required inputs for the wave prediction module are the speed and duration of winds, fetch distance, and water depth. Effective fetches were calculated according to the method described in the model. The wave prediction module of ACES is "based upon the fetch-limited deepwater formulas, but modified to include the effects of bottom friction and percolation" (Bretschneider and Reid, 1954). These relationships have not been verified. Depth is considered to be a constant in the equation in this module. Although the wind set-up in the lake will produce a slight slope ($3x10^{-4}$) in the water surface, an appropriate assumption for this analysis was to set the depth input as the average depth across the reservoir.

The required inputs for the wave theory module include wave height, wave period, breaking criteria, and water depth. The wave theory module is based upon calculations derived by Airy (1845) and considers the following set of assumptions:

- Waves are two dimensional (2D) in the x-z plane.
- Waves propagate in a permanent form over a smooth horizontal bed of constant depth in the positive x-direction.
- There is no underlying current.
- Fluid is incompressible, has no surface tension, and has no viscosity.
- Flow is irrotational.
- Coriolis effect is neglected.

2.4 Wave Run-up and Overtopping

The wave run-up module in ACES calculates the run-up that occurs when waves encounter a shoreline or embankment. Overtopping rates are also calculated in this module of ACES. The required inputs include wave type, breaking criteria, wave height, wave period, structure slope, structure height, slope type, and roughness coefficient. The cases modeled included both steep and smooth slopes with both smooth and rough surfaces. Roughness coefficients consistent with rip rap were used for the cases with rough surfaces.

Wave transmission and wave run-up modules were derived from physical model studies originally conducted for specific structures and wave climates (Leenknecht, 1992). General assumptions for the wave run-up on an impermeable embankment are:

- Waves are monochromatic, normally incident to the structure, and unbroken in the vicinity of the structure toe
- Waves are specified at the structure location
- All structure types are considered to be impermeable

- For sloped structures the crest of the structure must be above the still-water level
- For vertical and composite structures, partial and complete submersion for the structure is considered
- Run-up estimates on sloped structures require the assumption of infinite structure height and a simple plane slope
- The expressions for the transmission by overtopping use the actual finite structure height

2.5 Wave Transmission

The wave transmission module of the ACES model was used to determine the effects that internal breakwaters would have on wave growth, transmission of wave energy through internal breakwaters and on final wave run-up on the embankments. Required inputs include information on the breakwater, water depth, and incident wave height and period. Required inputs for the breakwaters include physical dimensions, median diameter of material, and porosity.

The wave transmission through a permeable structure (i.e. wave break) is estimated by relationships developed by Madsen and White (1976) and Seelig (1980). General assumptions for the wave transmission through a porous embankment are:

- Incident waves are periodic, relatively long, and normally incident
- Fluid motion is adequately described by the linearized governing equations
- The model can be used only for crests above the still-water line
- The model can be used for unbroken waves

The assumptions for wave run-up and wave transmission modules chosen to model the EAA Reservoir A-1 are appropriate. The design of the EAA Reservoir A-1 embankment will be both impermeable and taller than the combination of wave run-up, wave height, and wind set-up for the chosen design conditions. The wave transmission module gives the best predictions for shallow-water waves which fits the water depths of the EAA Reservoir A-1. Both modules are based upon physical model studies and their reliability is well documented.

2.6 Model Outputs and Results

The output files from the ACES model are provided in Appendix 5-18. The outputs produced wave prediction module include the effective fetch, adjusted wind speed, mean wave direction, wave height, and wave period. The outputs produced by the wave theory module include wave length, energy flux, and group velocity. The outputs calculated by the wave runup module include wave run-up, deepwater wave height, and wave steepness and overtopping rates. The outputs from the wave transmission module include the transmitted wave height.

3. WIND SET-UP

Wind set-up can be an important factor in determining freeboard requirements. Wind set-up occurs when wind blows in a relatively constant direction over the water surface. Shear stresses between the wind and water exert a drag on the water and pushes the water in the direction of the wind. When the water encounters a barrier such as a shoreline or embankment it piles up resulting in deeper water at the shoreline. Because the mass of water in the reservoir will be conserved, a decrease in water depth will occur at the leeward side of the reservoir to offset the wind set-up. However, the slope of the water surface is curved, not linear so the decrease in depth at the leeward side of the reservoir will not equal the increase in depth at the windward side of the reservoir.

Wind set-up will increase until there is a balance between the shear stresses on the water surface and a gravity induced return flow along the reservoir bottom. Wind set-up is a function of wind speed, fetch, and water depth. Wind set-up increases with wind speed and fetch but decreases with increasing water depth.

3.1 Model Description

The Sibul model was used to calculate wind set-up (USACE, 2004) and the results were added to the wave run-up calculations. The Sibul model is an empirical relationship based on the numerical model developed by Brater et al. (1996). The empirical relationship used laboratory and field data including data collected at Lake Okeechobee. The design conditions evaluated in this Technical Memorandum were not represented in the data used to develop the empirical relationship. Therefore, there is uncertainty in using the model for very high wind speeds. The following excerpt from USACE (2004) discusses the reduction in drag coefficient observed by Powell et al. (2003).

> *Experiments with high wind speeds over saltwater show an unexpectedly [sic] drop in the drag coefficient as speeds increase from approximately 90 mph to 114 mph (Powell). A possible explanation as suggested was that as wind speeds increase above hurricane force, the surface becomes layered in foam that may impede the transfer of momentum from the wind, essentially creating a "slip" surface. The reduced wind drag coefficient as observed appears to decrease to a range from 2.5 x 10^{-6} to 2.0 x 10^{-6} with the lowest expectation around 1.5 x 10^{-6}. . . . Remembering that these experiments were on saltwater, it is uncertain at this time whether or not these same observations may be expected on freshwater reservoirs.*

3.2 Model Inputs and Model Outputs

Wind set-up calculations were made for each of the cases evaluated. Calculations of wind set up using the Sibul model are included in Appendix 5-18. the calculations were made using an Excel spreadsheet which included both inputs and outputs.

4. REFERENCES

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